Wisconsin Highway Research Program

Investigation and Development of a Non-Destructive System to Evaluate Critical Properties of Asphalt Pavements during the Compaction Process

Wisconsin Highway Research Program
LIMITED USE DOCUMENT

University of Wisconsin – Platteville, Bloom Companies, LLC, and University of Illinois

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Summary Page

Project Title: Investigation and Development of a Non-Destructive System to Evaluate Critical Properties of Asphalt Pavements during the Compaction Process

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Indirect Cost Portion: 16 **%**

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4. Research Plan

a. Background

During the mid-1990"s, WisDOT specifications shifted from the primary use of cored samples to a nondestructive measurement of asphalt pavement density. While the current system has served to maintain a defined level of properties, concerns have been raised surrounding increased variability when attempting to properly evaluate: a) the influx of new materials going into bituminous pavements (ex: recycled products, binder additives, SMA, WMA, etc.); b) uniformity of mat compaction and densification (related to impacts on service life); c) a change in department emphasis toward pavement textures; d) rising construction zone safety issues (related to trying to decrease the amount of time and number of personnel needed to occupy the zone); and e) joint constructability and associated acceptance methods. All of these concerns suggest an opportunity to re-evaluate and enhance the current quality management system.

Presently, WisDOT employs the use of nuclear density gauges in its Quality Management and Acceptance Programs providing rapid density readings and allowing nondestructive pavement evaluation for spot locations on-site. However, the current system has shortcomings namely; procurement and handling of radioactive materials and using discrete point measurements to characterize the density of the entire pavement layer. Recent technological advancements indicate an opportunity for the department to expand beyond density as the sole parameter used to evaluate and accept HMA pavements. These technologies provide the potential to develop a system capable of collecting an increased number of diverse measurements, efficient data, off-site data retrieval, and real-time corrective actions during construction. Traditional knowledge combined with newer technologies also presents opportunities to define methods assessing entire pavement sections.

b. Research Objectives

The objectives of this research study, in two stages, are to:

Stage 1

(a) Define critical properties for measurement during compaction and justify their importance. Identify technology available to measure these products including potential suppliers and an estimate of cost.
(b) Develop evaluation systems using single or multiple technologies capable of measuring these critical material properties. Rank potential systems based on technical merits, cost, practicality, and other discerning factors.
(c) Prepare an interim report and present to the TOC within 6 months of the project start date, including a detailed description of a minimum two highest-ranked evaluation systems. The researcher and TOC will discuss the merits of each of these systems and select the system that will be used in field experiment specified in Stage 2.

Stage 2

(d) Develop additional detailed plan to complete a comprehensive field experiment designed to fully evaluate the system selected by the researcher and TOC at the completion of Stage 1.
(e) Perform fieldwork, collect and analyze supporting data.
(f) Develop specifications and guidance for implementation of the defined system.
(g) Prepare a final report documenting Stage 1 and Stage 2 actions.

c. Research Approach

Relatively few changes in conducting QA/QC monitoring have taken place over the past two decades. Furthermore, there is a growing trend by agencies to implement performance-related specifications (PRS), which include provisions to penalize or reward contractors according to the quality of their work (Hoerner et al. 1999). Recent research has focused on identifying rapid, nondestructive methods for quality control, such as NCHRP 10-65 which focused on non-destructive technology and evaluation (NDTE) for flexible pavements, and performance-related specifications (Transportation Research Circular 457). PRS is more related to performance monitoring than QA/QC, but requires similar in place measurements of materials characteristics (e.g., density), structural properties (e.g. modulus) and geometry (e.g. thickness). An important QC/QA parameter is density measurement, which is traditionally measured using a nuclear density gauge or core extraction. The effective cost of this procedure, measured in terms of time, labor, equipment and potential service disruptions, is orders of magnitude higher than an equivalent NDTE method if such technique is identified. Their importance stems from the non-invasive nature of the techniques and the anticipated rapidity and quantity of measurements.

The introduction of a compaction evaluation system using NDTE is highly beneficial; however, such advancement must provide information beyond that obtained with the current nuclear density gauge with increased reliability, accuracy, and efficiency. The ability of a proposed technology to provide information that is related to critical pavement characteristics determines its usefulness. Multiple NDT‟s present new opportunities, but also complicate the research effort as each method should be subjected to close scrutiny.

Measuring critical properties affecting compaction, such as density (including air voids) and temperature, requires a certain level of testing to yield reliable results that are useful to the project team. Current levels of testing and inspection are the accepted standard and built into the economy of a typical paving day, where a few dozen tests characterize the completed pavement, sometimes exceeding three or more lane-miles in length. The current data system is limiting the knowledge and understanding of a multi-faceted and very complex interplay of variables affecting the compaction process. Non-destructive testing provides an opportunity to attain higher levels of testing; however, the devices and labor requirements must be rapid, reliable, and cost effective.

The compaction process and paving mat itself can be thought of as a near-infinite population of data that is waiting to be mined. A newly paved 12-foot wide lane-mile of pavement having one-foot square density sites has a population of 63,360 test sites (5,280 feet x 12 feet). Simple random sampling of 750-ton lots has been created to obtain unbiased estimates of the average and standard deviation contained in the pavement mat. The rapid development of NDTs offer the project team a new window into the intricacies of never-imagined-before data feed. Intelligent Compaction technology generates thousands of data points in a single hour, and the industry is just beginning to harness the boundless capabilities of this technology. Figure 1 illustrates the how new data can be derived from the mat on a typical project.

Asphalt production and compaction must be viewed as a system and not individual fragmented processes meeting individual and separate specifications. Specifications can be challenging to construct since numerous factors must be simultaneously controlled during production, where all elements, such as mix volumetric properties, placement, and field compaction, must work together to meet adequate pavement performance. A systems approach will be undertaken to provide an effective means of interconnecting and organizing the NDT field measures and traditional lab tests. These components have an integral relationship and must collectively work together to achieve the desired outcome. By establishing a systems approach, the various components of the asphalt pavement design and construction system can be documented such that interrelationships can be measured and understood. The primary measure that serves as a common denominator among the HMA pavement system is density, as well as the densification rate. For example, a change in plant-produced mix volumterics (air voids, VMA, VFA, etc.) yields a change the produced materials that along with field compaction can cause satisfactory (or unsatisfactory) response to in-service performance resulting from insufficient, adequate, or over-compaction.

The following sections describe how the research will be accomplished through a series of seven work tasks. The first three tasks are planned in Stage 1, and the remaining four tasks in Stage 2.

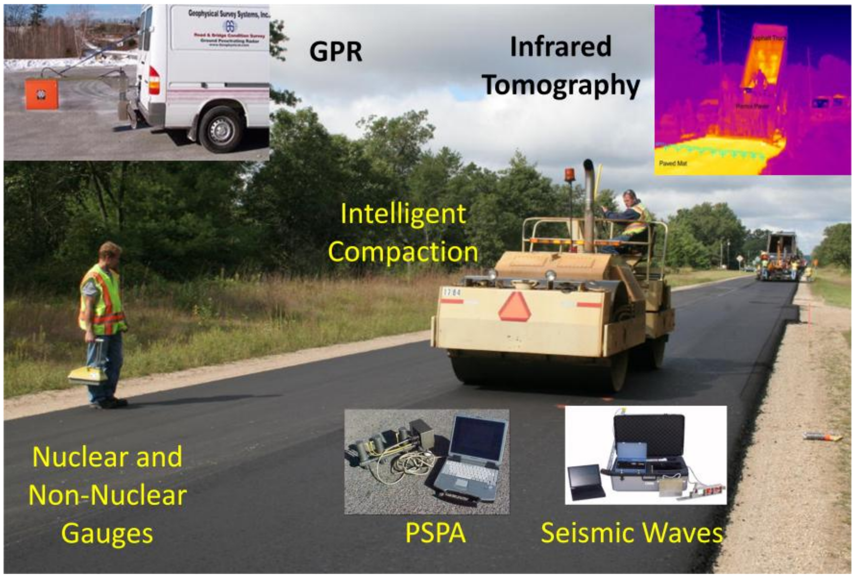

Figure 1. Non-Destructive Technologies on a typical Bituminous Paving Project

Task 1. Literature Review

The objective of Task 1 is to identify, collect, and perform a review of literature relevant to non-destructive technologies that can evaluate critical properties during the asphalt compaction process. The literature search will be conducted to justify the need for this research project or determine that the available technology is not capable at this time of providing beneficial information. This task has been subdivided into two subtasks for project efficiency: (1) Define Critical Properties and (2) Identify Available Technology.

Subtask 1.1. Define Critical Properties

There is a broad body of knowledge that has defined numerous properties critical to asphalt pavement compaction. Years of experimenting and evaluating pavement performance have derived critical properties affecting HMA pavement compaction. Several initial properties and accompanying importance are enumerated in Table 1. This listing serves as a beginning point and will be expanded during the execution of Subtask 1.1. A brief discussion of the presented properties follows.

Surface Texture

Paver segregation is a potential problem on any project, and has been observed in a number of states across the country. The paver manufacturers have been quite responsive and have developed retrofits to correct segregation sources within the paver. In some states, these retrofits are required. Thus, the non-destructive system should incorporate qualitative and/or quantitative measures for surface texture.

Moisture

Moisture content in the mix significantly influences the measurements from different technologies as it may affect the dialectic constant. In a recent study sponsored by the WHRP, moisture presence in the mixture appeared to significantly influence the density measurements when using non-nuclear density gauges (Schmitt et al., 2006). In a recent NCHRP study, the moisture content showed significant influence of the reading of the GPR and Electric Density Gauge (EDG) (Von

Quintus et al, 2009). Both studies agree on the effect of moisture on the reading from PQI models. Furthermore, the NCHRP study highlights that the moisture content influence measurements from the Geo Gauge, PSPA, and DSPA. A report by the Oklahoma State University and Oklahoma DOT (2009) indicates that the presence of moisture influences the density measurements when using most models of the Air Induced Density devices. However, all studies propose calibrating the devices to the specific mixture to account for the effect of moisture.

Table 1. Partial Listing of Critical Properties Affecting Measurement and Reporting of Compaction

Property (1)	Importance (2)
Surface Texture	• Indicator of segregation or material pulling apart • Function of gradation; fine- or coarse-graded • Depth of probe measurement • Use of surface fillers (water, sand, gels, etc.) have been used during nuclear density measurement to adjust for texture
Moisture	• Effect on asphalt binder adhesion • Influence on electrical impedance from non-nuclear density gauge reading process
Layer Thickness	• Effect of lower pavement layer or base on readings • Interference with non-nuclear electro-magnetic field • Uniformity • Function of ability to achieve pavement smoothness
Mat Temperature	• Ability to achieve density is a function of mat temperature • Equipment characteristics have a contributing effect
Pavement Base	• Modulus or strength for compaction • Material composition
Source Aggregate	• Effect on NDT operations • Shape, texture, angularity, interlock with ability to compact
Sampling Location	• Complete randomization or Roller width randomization • Blocked randomized designs for joints, roller pass, full mat width
Reporting Statistics	• Sample Size, Variability, Tolerance, Risk • Variance components: Materials, Production, Sampling, Testing

<u>Layer Thickness</u>

Layer thickness has an effect on the ability to achieve density and pavement profile (smoothness). Several states have investigated the effect of layer thickness on compaction, such as Florida, Mississippi, and Wisconsin. Previous work by the Florida DOT and NCAT showed that for a given compactive effort, an increase in lift thickness resulted in an increase in compacted density (NCHRP 2004). A WHRP study by Russell et al. (2005) confirmed specification and construction manual recommendations that the thickness-to-NMAS ratio be within a range of 3:1 to 5:1. Al-Qadi et al. (2001) were the first to report a technique to measure the in-situ dielectric constant of asphalt mixture using GPR, where the availability of such data allows accurate prediction of pavement layer thickness without field coring. The most recent study on predicting in-place asphalt mixture density using GPR was conducted by Al-Qadi et al. (2010). Compared to previous researchers who used the empirical exponential model between the void content and dielectric constant of asphalt mixture, they developed the models between the bulk specific gravity and dielectric constant of asphalt mixture, utilizing electro-magnetic mixing theory. These published findings suggest that the non-destructive evaluation system acknowledge layer thickness and NMAS.

Mat Temperature and Equipment Characteristics

Mat temperature and characteristics of the paving equipment have an impact on compaction. Numerous publication sources have documented this fact ranging from NCHRP research project findings, Expert Task Group/AASHTO recommendations, NAPA publications, and individual State experience. A majority of the publications have focused on control of mixtures using field laboratory testing to achieve field performance, while the remaining dealt with compaction. NCHRP (2007) highlighted the fact that paving contractors have learned that there is not one solution that works on all paving projects to achieve compaction, but they do have an array of possible solutions. They must be flexible and adjust on the fly to deal with changes in the mix, such as changing rollers and roller patterns. A Nebraska DOT study by Yong-Rak (2007) investigated the use of infrared tomography to develop a practical and economical method of preventing and managing HMA thermal differentials, A WHRP study determined factors affecting field density gain (in rank order) were mat temperature, number of roller passes, roller type, vibratory setting, and PG binder grade (Schmitt et al. 2009). These published findings suggest that the non-destructive system should acknowledge roller characteristics and mat temperature in system protocols.

Pavement Base

NCHRP Report 626 shows that the readings of the PSPA are influenced by the modulus of the base layers. On the other hand, the GPR is reported to be the most reliable technology in determining the base layer thickness. However, the ability of this device is highly dependent on the presence of a permeable lift in the pavement structure.

Source Aggregate

A report prepared by the University of Utah for a pooled fund study on the evaluation of non-nuclear gauges to measure density of HMA pavements clearly indicated that the aggregate source and gradation influence the reading on PQI measurements (Romero et al. 2002). This is because of changes that may take place in the dielectric constants. In NCHRP Report 626, the DCP is reported to be very sensitive to the aggregate source and gradation, while the GeoGauge shows minimal sensitivity (Von Quintus et al, 2009).

Sampling Location

Collecting samples from the compacted mat is an important consideration in any specification or construction manual. Randomization is used to protect against “trying to be fair” when collecting samples or measurements. The location on the mat has an impact on the sample. In a Texas DOT study by Estakhri (2006), reported densities near the unconfined edge averaging 6 to 7 lb per cubic foot below the densities taken at the center of the mat. Joint densities continue to be a problem in some states, but there are a number of alternatives to address them, including changes in rollers and roller patterns, proper raking of the joint material, use of wedge or notched joints, sealants, and echelon paving (although not practical in certain projects). Specifying a joint density requirement can help focus attention on the problem. Instituting a joint density specification should be done in a step-wise fashion so that both the contractor and the agency can develop a sense of confidence in the specification. As a result, the non-destructive system should acknowledge sampling location.

Reporting Statistics

Quantifying the statistical properties of the compacted properties is necessary to characterize what is being paved or what have been paved. Wisconsin DOT currently uses the statistical average to determine pavement density compliance (WisDOT 2010). The current WisDOT nuclear density specification was reviewed and critiqued in a prior WHRP study (Schmitt et al. 2006), and it was determined that the current n=7 sample size, coupled with a 95% probability level (5% risk) and mat standard deviation of 2.0 pcf, yielded a confidence interval of ± 1.5 pcf, and ± 0.9 % density. Based on a sample size of n=7 and mat standard deviation of 2.0 pcf, the probability level of the finding the average density within ± 1.0 pcf was estimated to be 81.4%. The probability level of the finding the average within ± 0.5 % density was 70.4%. This indicated that both WisDOT and contractors are exposing themselves to greater risk than the recommended 5% level. Risks can be reduced by increasing sample size, reducing variability, increasing the tolerance, or combining two or more of these approaches. Thus, the non-destructive system must build in accurate reporting statistics for compacted properties.

Subtask 1.2. Identify Available Technology.

Subtask 1.2 will focus on identifying non-destructive technologies, their properties, suppliers, and associated costs. The research team will carefully review and evaluate existing and emerging NDT and geophysical examination methods, hardware, and software to determine the overall appropriateness of each to address the needs identified in Task 1. The review will be based on personal experience and contacts of the research team, extensive literature review, and communications or visits with leading recognized NDT, sensing and transportation organizations related to the in-situ measurement of bituminous mix densities. A database will be developed for published and unpublished literature for critical evaluation in Task 2. Members of the research team have prior working knowledge of NDTs and field evaluations, as evident by recent studies by Al-Qadi et al. (2010) and Schmitt et al. (2006).

Table 2 represents a partial list of potential non-destructive testing (NDT) devices for asphalt pavements (not unbound materials) reported in the literature. Since there is a rapid development in these technologies, flexibility is needed in the final decision regarding their use in the field study.

Task 2. System Design Evaluation

The objective of Task 2 is to critically evaluate candidate nondestructive technologies for measuring material and compaction properties. First, a list of potential non-destructive tests that have the capability of characterizing the compactability of the mixture in the field will be compiled. It is anticipated that the literature search will yield additional information from these tests that may be related to mixture long-term performance. Then, candidate tests obtained from the literature will go through a systematic evaluation such that they can be ranked accordingly. The evaluation process of the candidate tests will include key parameters that are important to field measurement as well as relevance of data output. These parameters may include, but not restricted to, the following list:

1. Portability of the test.
2. Complexity of execution in the field.
3. Time required to conduct each test
4. Degree of training required.
5. Initial cost as well as life cycle cost.
6. Environmental limitations (temperature, rain, etc.).
7. Number and types of mixture performance indicators obtained.
8. Reliability of data collected.
9. Committee-approved test protocols (ASTM, AASHTO, ASCE, IEEE, etc.).

A weighted rating scale from 1 to 10 will be given to each of the parameters listed above, as well as any other parameter added during the literature search. This score will allow objective discussion of the considered technologies. The analysis of these candidate tests and their potential of enhancing the quality of the field data will be recommended in a report for the next stage of this project.

Table 2. Partial Listing of Candidate Non-Destructive Technologies for Compaction

Index (1)	Non-Destructive Technology (2)	Point or Continuous Measure (3)	Features (4)
1	GPR, Ground Penetrating Radar	Continuous	Provides continuous data concerning layer thickness, underlying pavement profile, and moisture.
2	PQI non-nuclear density gauge	Point	Measures pavement density and moisture using electrical impedance. PQI is more sensitive to moisture and less sensitive to changes in mat density than non-nuclear PaveTracker and traditional nuclear density gauges.
3	PaveTracker non-nuclear density gauge	Point	Measures pavement density and moisture using electrical impedance. Robustness to moisture and variability consistent with cores and nuclear density gauge are important features with this non-nuclear device.
4	Infrared tomography	Point	Measures temperature using infrared camera receptors across mat which can be related to mix variability and potential segregation.
5	Acoustic emissions	Point	A technology with efficient detection of a flaws under loading, but considered problematic around heavy equipment.
6	Roller-Mounted Density/Stiffness Devices	Continuous	A direct approach to continuously measure pavement densification and stiffness across the mat in real-time.
7	ROSAN, Road Surface Analyzer	Point	An efficient means of surface textural measurements, particularly with tined PCC pavement. It offers a new way of measuring asphalt pavement texture, but requires research and development.
8	Magnetic Tomography	Point	Provides a measurement system to map the pavement structure, but has no direct measure with mechanistic properties.
9	SPA and PSPA – Seismic and Portable Seismic Pavement Analyzer	Point	A tool to measure the moduli of the pavement structure that is consistent with the new mechanistic design methods.
10	SASW – Spectral Analysis of Surface Waves	Point	A seismic testing method used for assessing the stiffness and the depth of road pavement structures including the subgrade layer.
11	Permeameter	Point	Measures the flow of a media (air or water at this point in time) through the compacted asphalt. Permeability has an inconsistent relationship with density.

Task 3. Interim Report

A report summarizing the outcome of Tasks 1 and 2 will be prepared and delivered to the WHRP Panel. Based on the findings, a work plan, associated budget, and schedule for a combined field and laboratory experiment to evaluate the nondestructive system in Stage 2 will be developed and submitted. According to the RFP and proposed project schedule, the Interim Report will be submitted to WHRP within 6 months of the effective date of the contract.

Task 4. Amplified Work Plan

The objective of Task 4 is to design and finalize a field experiment to collect field data from actual construction projects. This will provide data necessary to develop a holistic compaction system with nuclear density gauges and appropriate non-destructive devices or systems. Information from the literature review will be used to assist in the development of the experimental design as well as the feedback from the WHRP panel. The work plan will be approved by the WHRP before field data collection begins.

Task 5. Field Data Collection and Analysis

The objective of Task 5 is to implement the experimental design developed in the previous task on actual construction projects. The following subtasks describe field data collection, lab testing, and analysis.

Subtask 5.1. Field Data Collection

The research team will receive work plan approval from WHRP before commencing this task. The PI will communicate directly with WisDOT and contractor project staff to determine the feasibility of conducting the field data collection on the candidate project. An advantage of this work proposal is that Bloom Companies may be the selected consultant and contract administrator for the host project, increasing efficiency and communication. Bloom Companies may contract with other venders or labs to conduct the work as appropriate and approved by the WHRP panel.

Tentatively, a minimum of three projects will be used for data collection, with emphasis on the gradation and surface texture of the material. Coarse-graded and fine-graded SuperPave^{TM} mixtures, along with SMA mixtures, will be identified per coordination with WHRP panel. One of the mixes will be selected to vary the layer thickness and base support. This will total five additive sections (not 12 multiplicative), as shown in Table 3. However, the actual number of projects will be limited by chosen NDTs and available budget resources. The research team is open to partnering by contractors, suppliers, or agencies (FAA, FHWA, etc.) where equipment is donated for a demonstration project, such as an Intelligent Compactor or non-nuclear density gauge

Table 3. Design Levels for Three Project Factors

Factor (1)	Level (2)	Description (3)
Gradation	3	Fine-Graded, Course-Graded, and SMA
Pavement Thickness	2	Uniform and Variable
Base type	1	Aggregate or Concrete
Total Additive Combinations	5	

It is important to note that there are more primary factors. Additionally, for each factor there could be more than two levels. The design included in the table is to assure a reliable factorial analysis within preliminary budget constraints. Furthermore, this design allows for isolating the variability due to device limitation from the other sources of variability within the study. This will help in conducting a sensitivity analysis on the results to recommend the more promising devices as one of the outputs of this study.

The research team will approach different contractors ahead of the construction season to collect the needed mix design information and materials. This task will be conducted with the help of the technical oversight committee (TOC) or the project oversight committee (POC). This will allow the research team to select field project of variable properties. Statistical means will be used to allow for inclusion of a large number of variables in the study while covering only few field projects to meet the study objectives as well as fund availability.

A statistically-based field sampling plan will be developed that provides a sample size within the budget and resource constraints. A randomized blocking design will be employed on each project to isolate on different offsets from centerline and stationing from beginning of rolling zone. Traditional QMP randomization may not offer the flexibility necessary for evaluation. Density readings will then be taken at each test site or mat area with a nuclear density gauge and approved non-destructive devices. The nuclear density gauge will serve as the reference „gold standard" for this study. Benchmarking non-destructive devices against the traditional nuclear density gauge is extremely important. The nuclear density gauge will be operated by technicians certified under existing WisDOT HTCP NucDens-I program. Both the PI and staff of Bloom Consultants, LLC, are certified NucDens-I. Cores may be sampled if the GPR is chosen for evaluation, since at this stage of technological development; calibration with the core is the most accurate method. However, recent studies by Dr. Al-Qadi of the research team showed the ability of GPR to measure density of bituminous mixes based on knowing the components.

Subtask 5.2. Lab Testing

Lab testing will be conducted on plant-produced loose mix to evaluate compactive effort using the SuperPave™ gyratory compactor. The method of evaluating the compaction effort in the laboratory will follow procedures in the final report of WHRP implementation project 0092-06-08, *Implementation of Using the Gyratory Compactor to Evaluate Mechanistic Properties of WisDOT Mixtures* (Faheem et al. 2008). The aim of laboratory testing is to provide a controlled evaluation of the mixtures. This will serve as the basis upon which the examined nondestructive testing devices will be evaluated. The laboratory evaluation will also serve to evaluate the different construction techniques by identifying the deviation of the laboratory measurements from the expected results seen in the field. Traditional volumetric measures and compaction indexes (CEI, CFI) will be reported from lab testing. Sampling of the loose mix will be randomly acquired at different production times during a given day corresponding to the field testing locations.

Subtask 5.3. Data Analysis

The objective of Subtask 5.3 is to model the collected data to create relationships among the compaction measures identified in Task 4. The sampling design largely drives how a rigorous analysis and statistically-valid model development can proceed. The modeling process will consist of two phases: a preliminary investigative phase and a model-building phase. The preliminary phase will use analysis of variance (ANOVA), scatter plots, and correlations to identify key input factors having an effect on the compaction system. The latter phase of model building consists of simple and multiple regressions, using key input factors to build models that express the quantitative relationship among the output factor (density or other measures).

New measures from NDTs will be correlated, such as layer thickness deviations from GPR, temperature gradients from Infrared Tomography, and a variety of measures from Intelligent Compaction (stiffness, pressure, amplitude, frequency, speed, etc.). One of the most critical factors influencing field-compacted density is the number of passes made in a rolling operation and mat temperature (Schmitt et al. 2009). A schematic diagram of a 5-pass rolling pattern using three rollers (vibratory breakdown, vibratory or pneumatic intermediate, and finish) is shown in Figure 2. The number of passes is determined by numerous factors, such as the compactibility of the HMA, layer thickness, layer moduli, length of rolling zone, width of the roller, width of the paving lane, roller speed and weight, vibratory frequency and amplitude, cooling rate of the mat, temperature of subbase, and ambient temperature and wind speed.

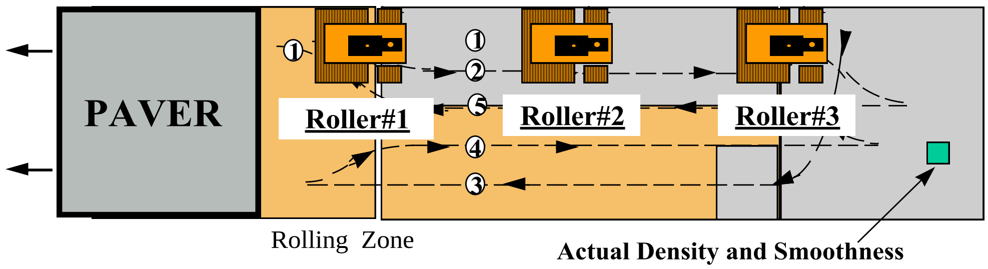

Figure 2. Rolling Zone and Path Pattern Schematic

Simple statistics will also be evaluated. Different sample sizes have correspondingly different risk levels. During development of sample sizes for a lot, risks to both WisDOT and the contractor will be evaluated for different sample sizes. Both the agency and contractor share risk during the acceptance process, designated as the α and β risks. The α risk affects the contractor, since it is probable that the agency may reject, what is in fact, acceptable work. The β risk affects the agency, since it is probable that the agency may accept, what is in fact, rejectable work. These risks are a function of several attributes including: (1) sample size, (2) Acceptable Quality Level and Rejectable Quality Level, (3) estimated mean of the acceptance decision, and (4) variability.

Task 6. Develop Specifications and Guidelines for Implementation

The objective of Task 6 is to develop preliminary procedures and guidelines for use of nondestructive technologies in specifications and construction manuals. Findings from the data analysis will largely determine appropriate implementation for practical and effective quality control and verification using these technologies. A dispute resolution system will also be described. A discussion of the strengths and weaknesses of the recommended systems will be included. Practical issues will also be addressed, such cost and availability of equipment, complexity of use or personnel training, time requirements for testing, data download and transfer, and analysis of data. A discussion of the potential barriers for future implementation of the recommended system will also be detailed.

Task 7. Document Results and Submit Final Report

A final report that documents the research scope and outcome will be submitted. A close-out presentation is scheduled after submitting the draft final report to WHRP.

d. Anticipated Research Results and Implementation Plan

It is a goal that the research be ready for implementation at the conclusion of the study. Guidelines will be prepared to assist WisDOT, contractors, and consultants with implementation of identified nondestructive technologies. The guidelines will include the following:

- A construction manual that addresses the issues associated with the compaction system on construction projects.
- Management of project factors that have an effect on compaction control, such as pavement thickness, temperature, and base type.
- Calibration of non-destructive devices.
- Bias and offset procedures between multiple devices with available data.
- Special testing procedures for coarse- and fine-graded SuperPave™ mixtures and SMA mixtures.
- Recommended sampling and testing plan to achieve statistically-valid data for the QMP specification that manages risk to both the producer (contractor) and purchaser (WisDOT).
- Creation of a database for piloting a construction specification using the new system on highway construction projects.

e. References

Al-Qadi, I. L., Leng, Z., Lahouar, S., and Baek, J. (2010). "In-place Hot-mix Asphalt Density Estimation Using Ground Penetrating Radar," *Transportation Research Record*, TRB, National Research Council, Washington, D.C. (in press).

Al-Qadi, I. L., Lahouar, S., and Loulizi, A., (2001). "In Situ Measurements of Hot-Mix Asphalt Dielectric Properties," *NDT & E International Journal*, 34(6), pp. 427-434.

Estakhri, C.K. (2006). "Support for the Implementation of a Longitudinal Joint Density Specification for Hot-Mix Asphalt Concrete", Texas Department of Transportation, <http://tti.tamu.edu/documents/5-1757-01-1.pdf> accessed July 15, 2010, January 2006.

Faheem, A.F., A.J. Hanz, and H.U. Bahia (2008). "Implementation of Using the Gyratory Compactor to Evaluate Mechanistic Properties of WisDOT Mixtures", Wisconsin Highway Research Program, Project 0092-06-08, Madison, WI.

Kim, Y.-R. (2007). "Infrared Thermography-Driven Detection and Evaluation of Hot Mix Asphalt (HMA)", Nebraska Department of Transportation, <http://rip.trb.org/browse/dproject.asp?n=13596> accessed July 15, 2010, July 2007.

NCHRP (2009). "State DOT Management Techniques for Materials and Construction Acceptance", ISBN 0-309-06817-7, National Cooperative Highway Research Program, Washington, D.C., revised September 23, 2009.

NCHRP (2007). Practical Approaches to Hot-Mix Asphalt Mix Design and Production Quality Control Testing, Transportation Research Circular E-C124, Washington, D.C., 2007.

Oklahoma DOT (2009). "Longitudinal Joint Density and Permeability in Asphalt Concrete", SPR Report No. 2197, May 2009.

Russell, J.S., H.U. Bahia, K. Kanitpong, R.L. Schmitt, and J.C. Crovetti (2005). "The Effect of Pavement Thickness on Superpave Mix Permeability and Density", Final Report No. 05-05, Wisconsin Department of Transportation, Wisconsin Highway Research Program, Madison, WI.

Schmitt, R.L, H.U. Bahia, C. Johnson, and A. Hanz (2009), "Effects of Temperature and Compaction Effort on Field and Lab Densification of HMA", *Journal of the Association of Asphalt Paving Technologists 2009*, St. Paul, MN.

Schmitt, R.L, C. R. and H. Von Quintus (2006), "Non-Nuclear Density Testing Devices and Systems to Evaluate In-Place Asphalt Pavement Density", Wisconsin Highway Research Program Technical Report 06-12.

Von Quintus, H. L. C. Rao, R. E. Minchin, Jr., S. Nazarian, K. Maser, and B. Prowell (2009). "NDT Technology for Quality Assurance of HMA Pavement Construction", NCHRP Report 626, Washington, D.C.

WisDOT (2010). <u>Construction Materials Manual</u>, Section 8, Wisconsin Department of Transportation, Madison, WI.

5. Time Requirements

The research described in this proposal will require a duration of 30 months, however, a majority of the research will occur in the first 18 months. With summer 2011 field testing only, the project should be completed by May 2012.

		2010			2011												2012												2013		
Task	Description	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	O	N	D
1	Literature Review																														
2	System Design Evaluation																														
3	Interim Report																														
4	Work Plan																														
5	Field Data & Analysis																														
6	Implementation Plan																														
7	Final Report																														

Figure 3. Project Schedule

6. Budget Estimate

It is estimated that the research be completed for $120,000.